REPORT

ON A

SUSPENSION BRIDGE

ACROSS THE POTOMAC,

FOR

RAIL ROAD AND COMMON TRAVEL:

ADDRESSED TO THE

MAYOR AND CITY COUNCIL OF GEORGETOWN, D. C.

BY

CHARLES ELLET, JR.

CIVIL ENGINEER.

(SECOND EDITION.)

PHILADELPHIA:

JOHN C. CLARK, PRINTER, 68 DOCK STREET.

1854.

REPORT

ON A

SUSPENSION BRIDGE

ACROSS THE POTOMAC,

FOR

RAIL ROAD AND COMMON TRAVEL:

ADDRESSED TO THE

MAYOR AND CITY COUNCIL OF GEORGETOWN, D. C.

BY

CHARLES ELLET, Jr.

CIVIL ENGINEER.

(SECOND EDITION.)

PHILADELPHIA:

JOHN C. CLARK, PRINTER, 68 DOCK STREET.

1854.

To the Honourable Senate and House of Representatives of the United States.

The Memorial of the undersigned, Members of a Committee appointed by the Corporation of Georgetown, to attend to its interests before Congress, respectfully represents that the people of said town, as well as of its neighbourhood, still experience serious inconvenience and injury from the loss of the Suspension Bridge at the Little Falls of the Potomac. Public opinion concurred to such an extent in favour of the erection of a Bridge at the point known as the "Three Sisters," that the Corporation, during the late recess of Congress, determined to engage CHARLES ELLET, Jr., Esq., to survey that site, not only to ascertain its general suitableness for a Bridge, but, also, the practicability of connecting roads with it from the North and South, both for National and local accommodation, at a moderate cost.

After making the survey, Mr. Ellet's opinion was so confirmatory of the certainty of these results, that the Corporation engaged him to prepare a general outline of the whole improvement, and, also, a neat plan of the proposed Bridge, and to have it engraved with a descriptive printed report and an estimate of its cost, attached. This work has been completed, and is herewith presented to your Honourable Body for such consideration as you may be pleased to bestow upon it.

Having the fullest confidence in the correctness of Mr. Ellet's opinion, and that a Bridge can no where else be erected so as to secure the great objects of promoting the general welfare and public convenience, without inflicting loss or injury upon any party however remotely interested in the improvement, we most earnestly and respectfully pray that Congress may adopt the same, and make an appropriation for its seasonable erection.

In conclusion, your Memorialists also beg leave, most respectfully, to renew the expression of the opposition of the People and Authorities of Georgetown to the erection of any more bridges below their harbour, as well as to any plans or schemes for other purposes that may invade the rights to which they are justly and naturally entitled.

H. ADDISON, A. H. PICKRELL,
WM. H. TENNEY, H. C. MATTHEWS,
WILLIAM S. NICHOLS, MARIMIS WILLETT,
F. W. RISQUE, ROBT. OULD,
A. H. DODGE, JUDSON MITCHELL,
B. J. SEMMES.

GEORGETOWN, D. C., *December 22d*, 1852.

REPORT.

To the Mayor and City Councils of Georgetown, D. C.

Gentlemen,—I propose to recommend a Wire Suspension Bridge as the most appropriate plan that can be adopted for a bridge across the Potomac, whether it be intended for the accommodation of common travel or of rail roads.

I am aware of the prejudice which has existed, and may still exist, against the application of the suspension bridge for rail road purposes; but as it is only a prejudice, I feel sure that it will give way before reflection and sound argument. It is but a very short time since a greater prejudice prevailed against the adoption of suspension bridges for common travel; and fifteen years ago I met with no little difficulty in convincing the public of their practicability and safety even for that purpose. It is, indeed, but thirty years since a great effort was required to satisfy the British Parliament of the practicability and safety of a common road bridge of less than 600 feet span, though it was proposed by the most famous engineer of his day; and nearly all the practical science and skill of the country was convened to testify for or against the plan.

But truth and common sense prevailed; for, in the long run, Truth always prevails. I hesitate not, therefore, to propose a rail road suspension bridge for crossing the Potomac. Its practicability and security are demonstrable; and I regard it as not only the most appropriate, but by far the most beautiful and imposing structure that can be placed on the site proposed. I shall not hesitate on account of prejudice. Prejudices must yield before proof, conviction and expediency.

OF THE SITE OF THE BRIDGE.

The position selected for the construction of this bridge is a point about half a mile above the Georgetown aqueduct. The river is here, at common high water, 1030 feet wide on the surface. The bed is generally of rock, and the depth very variable.

At a point about 450 feet from the water's edge, on the Maryland side, several masses of granite protrude above the surface of the river in all stages of the water. These masses, called THE SISTERS, are surrounded by a sand bar, of which a portion is bare at low tide.

The high water depth of the river between these protruding rocks and the Maryland shore, is about 25 feet; but between the rocks and the Virginia shore, it increases to 85 feet. This great depth is found at the distance of 150 feet and 200 feet from the shore, where the bottom is of rock and extremely rough and irregular.

The great depth of the river, and the want of uniformity in the shape of the bottom, would add largely to the cost of any ordinary stone or iron bridge, re-

quiring the support of piers. But the excessive depth offers no additional impediment to the construction of a suspension bridge.

On the Maryland shore is the Chesapeake and Ohio Canal, of which the surface is 75 feet wide, and elevated 34 feet above common high tides.

By the side of the canal is a public road, raised a few feet above the water, and separated from it by a parapet wall.

The use both of the canal and road must be protected, in any plan which may be adopted for the bridge.

On the southern shore, the bridge stands on a base of uncovered granite; and on both shores the cables will be anchored in the solid rock.

The site of the bridge has been chosen with a view to avoid any obstruction to the navigation of the Potomac, and to relieve Georgetown of the impediments which it is alleged have been formed in the channel of the river since the construction of the dilapidated Long Bridge, and the contraction of the water-way; and, at the same time, to afford a convenient approach for the rail road trains and common travel crossing the river on the great northern and southern line.

The chief objection that has been urged against this location, is the fact that any rail road which may be projected to unite the road leading from Baltimore to Washington, with those leading from Alexandria to the south and south-west, must be carried out of the direct line in order to cross at this point. The distance is supposed to be about three miles greater than it might be if the new bridge were placed on the site of the obnoxious Long Bridge. I am of opinion, however, judg-

ing from the map of Washington and my personal knowledge of the localities, that the actual increase will be less than three miles. Yet, in the absence of precise information, I shall assume three miles as the true measure of its value.

This increase of distance might appear to be a substantial objection to the site proposed. Yet it is, in my judgment, perfectly clear, that if the object were to locate the connecting rail road with a view to the least possible loss of time to the through traveller, this is precisely the point at which the engineer would wish to cross the Potomac. A bridge on this site, as already stated, can be conveniently approached by rail road lines from both directions. There is no dense population on the route of the connecting road to retard the trains, or to prevent the highest desirable speed. There is here no long bridge to be traversed at a slow rate, nor draws to interfere with the passage of trains, nor streets nor crowds to be provided for. The through trains may therefore maintain their full headway.

The line of the road, crossing at the proposed site of the bridge, will pass immediately on the western border of Georgetown; it will then sweep round to the north, skirting the town in that quarter, and affording every convenience that can possibly be derived from a rail road without carrying it actually through the place.

It will cross over Rock creek near the foot of the new cemetery, and traverse the whole length of Washington, through the northern wards, from Rock creek to the Baltimore Rail Road—keeping near enough for the accommodation of the city, yet far enough north of the pre-

sent built up district, to relieve the public of the danger and nuisance of a through rail road within the city.*

The ordinary time on a good rail road cannot now be assumed at less than a mile in two minutes, or 30 miles an hour. Much higher speed than this is made on many English roads, and if less than 30 miles an hour is now suffered on the main lines of this country, it will not be long tolerated, after connections are formed between the finished roads east, and those west of the Alleghany mountains, and the great flood of western travel begins to be vented.

To traverse the three miles assumed to be lost by crossing the Potomac above Georgetown, and passing north of Washington, will involve an apparent loss of *six minutes* in the through time;—in the supposition that no corresponding loss will be incurred by crossing at or near the site of the abandoned Long Bridge. But there *will be* material losses on any line; and these losses must be properly noticed in any just comparison.

If we cross at the site of the Long Bridge we shall meet with the following detentions, which are avoided on the line proposed.

1. The loss of time required to cross a bridge *one mile longer* than the proposed Georgetown Bridge, at a

* I do not wish to be understood to express any opinion adverse to rail roads in cities along great thoroughfares, such as Broadway, in New York, or Pennsylvania Avenue, in Washington, where the roads are properly devised for the local accommodation of the city. On the contrary, I am of opinion that *a branch* from the main line might be carried along Pennsylvania Avenue, under proper municipal control, with great advantage to the public, and without impediment to the through travel.

speed of, say eight miles an hour: this loss will be 5½ minutes.

2. The loss of time in passing one mile through the built up part of Washington, at 8 miles an hour; which would also be 5½ minutes.

3. The loss to be encountered in case the draw should chance to be raised for the passage of a vessel on the approach of a train; which loss would vary with circumstances.

It is easy to perceive, without going into a minute investigation, that the through trips can be made quicker, on a rail road which crosses the Potomac where it is narrow, and above the navigation, and which passes north of Washington, than on any line whatever leading through the heart of the city.

It is not my purpose, I repeat, to take general ground against local rail roads in cities, when properly designed for the accommodation of the cities. Yet I am clearly of opinion, that, at an early day, the *through trade and travel* of this country must be accommodated by lines which pass around the great cities, and avoid the obstruction which a dense population offers.

In the case before us, it is my opinion that the best speed and the best time can be made on a through road passing west of Georgetown; and, moreover, that the site selected for the proposed bridge is the only place where the Potomac can be crossed by a rail road without injury to the navigation, and affording just ground of complaint, unless the structure be a suspension bridge of very great height and span and cost.

OF THE PLAN OF THE BRIDGE.

In designing a plan for this bridge, I have concluded not to make any use of the masses of rock which rise up from the bed of the Potomac, and form The Sisters. There would be, certainly, a trifling economy in inserting a pier and dividing the span; but such an arrangement would detract greatly from the beauty and magnificence of the structure, and form a fixed point to be exposed to the perpetual assault of the river.

The distance to be bridged, from shore to shore, in an average stage of the river, is 1000 feet; though at high water it is 1030 feet; and after careful inquiry and full consideration, I have decided to span the entire water-way with a single arch.*

The length of this arch, from centre to centre of the supporting towers, is 1000 feet—or ten feet less than the span of the Wheeling Bridge. It will clear the entire water-way, with the exception of a few feet of the beach which is covered by the tides.

The elevation of the flooring is 60 feet above the high water surface of the river.

On the Maryland shore, a stone arch of 85 feet span will bring the bridge to the tow-path of the Chesapeake and Ohio Canal. Another arch of 85 feet, will clear the Canal and its tow-path. A third arch, of 35 feet, will clear the public road, and reach the high ground north of the Canal.

* Since writing this, I have made an estimate of the cost of a rail road bridge of equal strength and rigidity, in two spans, with a pier. The cost of such a bridge will be $240,000.

On the opposite, or Virginia shore, a stone arch of 85 feet brings the bridge to the rocky slope of the hill. These stone arches are all elliptical, and rise 15 feet above the skew-backs.

The breadth of the flooring will be 32 feet in the clear, between the parapets of the foot-ways.

Ten feet in the centre of the flooring is appropriated to a railway track; 8½ feet on each side thereof, to carriage-ways; and 2½ feet outside of the carriage-ways, to foot-ways.

The foot-ways are carried around, outside the towers, and protected by a projecting parapet, as shown in the annexed engravings.

This bridge, thus arranged, will be supported by 16 wire cables, each of which will be composed of 1350 strands of No. 10 iron wire—or wire which weighs *one-twentieth of a pound* per lineal foot.

The diameter of each of the 16 cables will be about six inches. Their length will be 1400 feet. The deflection of the cables, below their respective points of suspension, will be 65 feet.

On the south side of the river, or Virginia shore, the road will curve to the east, after leaving the bridge, and follow the slope of the hill.

On the north side, it will rise with a grade not exceeding 50 feet per mile, and pass through a depression in the hill forming the heights of Georgetown, by a short tunnel, or a cut about 65 feet deep at the summit.

No difficulty whatever is presented to the continuation of the rail road, from this site, on either side of the river.

On the Maryland side, a branch track, half a mile long, turning off north of the canal road, will bring the accommodation cars to a point on Bridge Street nearly opposite the aqueduct and convenient for the local business of Georgetown.

OF THE FLOORING.

In the plan of the flooring herewith presented, arrangements are made for a railway track. It may happen, however, that for want of legislation, the bridge will be built before the rail road connexion is formed at Washington. In that case the framed girders which separate the track from the carriage-ways, and the stone flagging with which the track is covered, and four of the cables, may be left out, until the railway needs accommodation. The first cost of the bridge would thus be reduced about $50,000.

In the plan, as prepared and submitted, the railway is separated from the carriage-ways by heavy timber girders, 3½ feet high. Under the flooring, and corresponding with these upper girders, are two suspended girders, 18 inches deep. These upper and lower girders are firmly drawn together by iron bolts passing through them both, and through the heavy joists of the flooring. The intention of these girders is at the same time to give weight to the structure, to protect the common travel from the trains, and also to distribute the weight of the trains along the flooring, and break the vibrations which are experienced in lighter and looser structures. The vertical girders are sustained laterally by knees bolted to them and to the heavy

joists beneath. Between these girders is the railway track, supported on transverse sills, in the usual mode —the space not occupied by the sills being covered with a stone flagging.

The flooring of the carriage-ways is composed of two courses of $2\frac{1}{2}$ inches plank, laid longitudinally with the bridge. The upper course is of oak. The lower course of pine.

The foot-ways are raised 8 inches above the carriage-ways, and covered with a single course of $2\frac{1}{2}$ inches pine plank.

Outside of the foot-ways is a lattice parapet, well bolted to the timbers below, so as to assist somewhat in stiffening the structure and in distributing the transitory loans along the flooring.

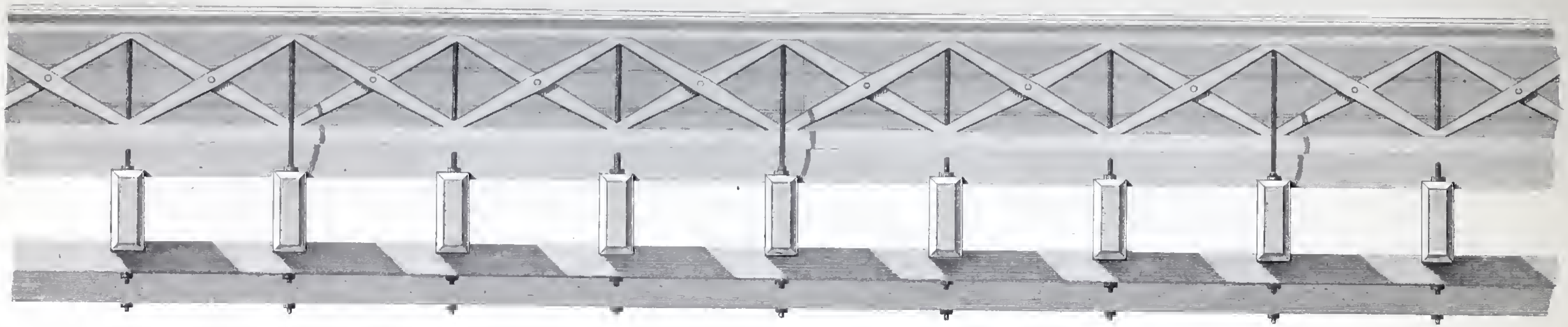
The details of the platform are exhibited in the annexed engraving, where the parts are drawn to a convenient scale.

The total volume of timber in each lineal foot of the structure, is $47\frac{1}{2}$ cubic feet. Of this volume we shall have of

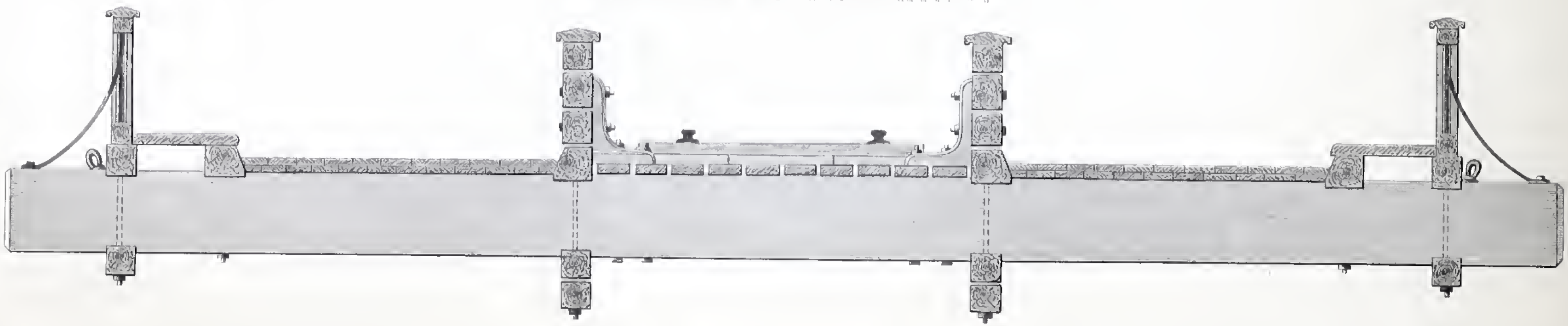
White pine, 40 cubic feet, at 35 lbs.	-	-	1400 lbs.
White oak, $7\frac{1}{2}$ „ at 60 lbs.	-	-	450 „
Total weight of timber in the bridge,			1850 lbs.

There will be no difficulty in substituting iron in place of timber, for the greater part of this platform; but as the timber in such a framing will last for many years, and may be easily renewed, I have not deemed it worth while to incur the additional expense which the use of iron would involve.

ELEVATION OF FLOORING.



SECTION OF FLOORING.



SCALE 5 FEET TO THE INCH.

Engraved by J B Neagy

There will be, in the flooring, in addition to the timber, a considerable weight of iron bolts and stone flagging. The total weight of the platform, including these items, will be as follows:—

Weight of Flooring.

Weight of timber, per lineal foot, as above,	-	1850 lbs.
Weight of iron in bolts, rails, and suspenders,	-	140 „
Weight of stone paving, - - - - -	-	230 „
Total weight of flooring,		2220 lbs.

OF THE TRANSITORY LOADS ON THE BRIDGE.

The transitory loads which will come on the bridge are not likely to exceed 150 tons at any one time; but in estimating the possible loads, with a view to determine the strength of the cables, it is proper, and, indeed, due to the public, to assume an extreme case. I shall therefore make the computation of the needful strength, and the cost of the bridge, in the hypothesis that the railway track may be occupied by engines and trains of cars from one abutment to the other; and that, at the same time, both the carriage-ways may be covered from one end of the bridge to the other with loaded teams. The cables must then be so proportioned that they will bear *thrice* the weight of the bridge, and *thrice* the tension produced by this load upon it, and still possess a surplus of force.

The weight of this load would be as follows:—

Maximum Transitory Load.

2 locomotive engines, each 18 tons,	- -	36 tons.
2 tenders, each 9 tons,	- - - -	18 ,,
40 freight cars, loaded, each 10 tons,	- -	400 ,,
100 carts, loaded, on the carriage-ways,	- -	90 ,,
100 horses, say	- - - - - -	56 ,,
Total transitory load,		600 tons.

This load will be distributed over a space of 1000 feet, making the increment of weight on each unit of length, or one foot of the platform, 1200 pounds.

This, it will be conceded, is an extreme supposition; for it is not at all probable that we shall ever see a bridge across the Potomac occupied at the same time, from end to end with loaded cars, on the central track, and with 100 loaded carts and 100 horses, on the side tracks. But to make this assumption, as the basis of calculation, is certainly to err on the side of safety; and it is therefore proper, even though it may seem to border on extravagance.

OF THE CABLES.

We have now all the elements for ascertaining the proper strength of the cables, or the ability of the cables proposed, to sustain the weight of the bridge, and the loads which may come upon it. And it is fortunate that, on this point, there need be nothing left for conjecture or speculation. The dimensions of the cables, or the quantity of material of which they must be composed, may be determined, where the weight of the bridge and its load are prescribed, with the most per-

fect certainty, by a calculation as reliable as anything in the circle of mechanics.

The total weight of the bridge, including that of the cables, is as follows:—

Total Weight to be supported.

Weight of the flooring, per lineal foot, - -	2220 lbs.
Weight of 16 cables, each composed of 1350 strands of wire weighing $\frac{1}{20}$ lb. per foot, - - -	1080 „
Total permanent load, per lineal foot, - -	3300 „
Add transitory loads, „ - -	1200 „
Total, or maximum load to be provided for, per lineal foot of flooring, - - - -	4500 lbs.

To ascertain the effect which will be produced upon the cables by this load, we will observe that the greatest strain is at the points of support, where its value is equal to the resultant of the horizontal tension, and the vertical or proper weight of the bridge and load. To calculate the tension at this point, we must first deduce the value of the horizontal strain from the absolute weight to be supported.

The vertical weight on each foot of the flooring, when the bridge is loaded, is, as above, 4500 pounds. The length of the flooring is 966 feet. The total vertical weight, then, is

$$4500 \times 966 = 4{,}347{,}000 \text{ pounds,}$$

or 2173 tons—the one-half of which, or 1086.5 tons, is supported at each bearing point of the cables.

But the vertical weight is to the horizontal tension,

as twice the sagitta is to half the span of the curve, or as

$$2 \times 65 : 500.*$$

The horizontal tension will then be

$$\tfrac{500}{130} \times 1086.5 \text{ tons} = 4179 \text{ tons.}$$

The resultant of these two forces will be

$$(1086.5^2 + 4179^2)^{\frac{1}{2}} = 4318 \text{ tons.}$$

Or, the greatest strain that can come upon any part of the cables, when the bridge is loaded with heavy teams and rail road cars, as above described, will be 4318 tons.

Iron wire of the size known as No. 10—or of such a diameter that a strand 20 feet in length will weigh one pound—if of good quality and free from flaws, will sustain a weight of about 1400 pounds. If we load strands of wire capable of bearing 1400 pounds with a weight not exceeding 400 pounds, we may regard any work supported by such strands as perfectly secure.

Now, I propose so to adjust the proportions of this bridge, that when there is a load of 600 tons on the flooring, and when the tension in the cables, all told, is 4318 tons, each strand of wire, found by experiment capable of bearing 1400 lbs., shall not suffer a strain exceeding 400 pounds.

The total strain is 4318 tons, or 8,636,000 pounds. The number of strands required to support this strain, with the degree of security implied by the condition, is

$$\tfrac{8636000}{400} = 21{,}590 \text{ strands.}$$

* For the usual formulæ for these calculations, see Note A.

The bridge will be upheld by 16 cables; and there will therefore be 1350 strands in each cable.

The total weight of the cables, per lineal foot, will be, from these data, at $\frac{1}{20}$ of a pound per lineal foot,

$$\frac{21590}{20} = 1079\tfrac{1}{2} \text{ lbs. per foot.}$$

The total weight of wire in the 16 cables, each of which will be 1400 feet long, will be

$$1079.5 \text{ lbs.} \times 1400 \text{ feet} = 1,511,300 \text{ lbs.}$$

or $755\frac{2}{3}$ tons.

The absolute strength of all the cables will be

21,590 strands × 1400 lbs.	=	30,226,000 lbs.
The maximum strain is, as above shown,		8,636,000 lbs.

Or, the absolute strength of the cables is to the greatest absolute strain which can come upon them, as $3\frac{1}{2}$ to 1.

Now when it is considered that the weight which is supposed to be on the bridge, in this calculation, very far exceeds any load that is ever likely to be collected on the flooring; and that the cables are so adjusted, in dimensions and in the mode of suspension, that they ought, if sound, to be capable of sustaining the weight of more than three such bridges and three such loads, before breaking, it will not be doubted that, on the score of strength, every reasonable precaution is taken, and the fullest allowance made.

The question might indeed, be raised, as to whether it is really practicable so to manufacture these cables, that the strands of wire of which they are composed may each be depended on to fulfil its share of the duty. On this score there is, however, no practical

difficulty. Every strand does in fact do its duty, in the cable, as completely as if it acted separately. Neither can there be any doubt of the soundness of the material; for every strand of wire used in the cables is necessarily subjected to a test, in the last drawing to which it must be subjected in its manufacture, much exceeding the greatest strain that can come upon it in the bridge.

The processes of protecting the material against oxidation, so as to preserve its original strength, have been tested by long experience; and there is now no reason to doubt that the wire cables of a suspension bridge, properly varnished, and protected externally by an occasional coat of paint, will be of almost indefinite durability.

The cables in this bridge will be anchored, on both sides, in the granite rock. The cost of anchorage will therefore be very small, and the security of the fastenings undoubted.

OF THE TOWERS.

The towers of this bridge are represented in the annexed engraving. They are each 128 feet high, measured from the surface of the river, at high water, to the bearing point of the cables. To the summit of the parapets, the height is 135 feet. The summits of the towers are 75 feet above the flooring of the bridge.

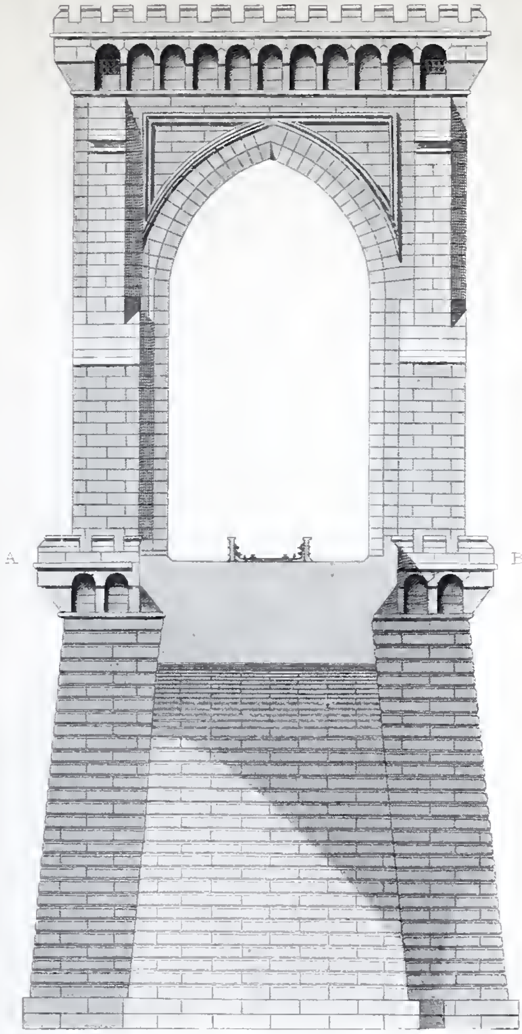
Each of the towers is 35 feet thick, and 64 feet wide, at the level of the water; and 10 feet thick, and 52½ feet wide, at the height of the saddles. They are pierced, at the level of the roadway, with pointed

SIDE ELEVATION OF TOWER.

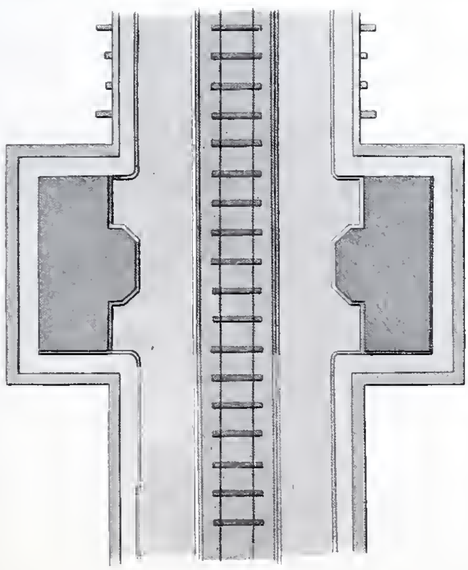
PLAN

SCALE 30 FEET TO THE INCH.

FRONT ELEVATION OF TOWER.



SECTION THROUGH A B



SCALE 30 FEET TO THE INCH

arches 27 feet wide and 54 feet high, for the passage of the railway and carriage tracks. The foot-ways are carried around, on the outside of the towers, and supported by a projecting cornice with an embattled parapet.

Each tower and abutment contains 4650 cubic yards of masonry.

The piers of the elliptical arches, which span the canal and the space between the northern tower and the canal, are 10 feet thick.

The total amount of masonry in the abutments, towers, piers, arches and spandrils, is 16,550 cubic yards. Of this volume 7100 cubic yards are in the abutments, 2200 cubic yards in the towers, and 7250 cubic yards in the arches, piers, wing-walls, and spandrils.

ESTIMATED COST OF THE BRIDGE.

We have now all the material needed for determining the cost of this bridge. And in making this estimate, as in arranging the plan of the structure, I have not deemed it at all expedient or proper to practice a close economy. It would seem to be more appropriate in designing a structure to be erected within sight of the Capitol, for the conveyance both of the rail road and common travel across the Potomac, on the great northern and southern thoroughfare, rather to seek to make the edifice a monument of strength and stability worthy of the site and its purposes. I shall therefore submit a liberal estimate and assume that a work of the first order is to be erected.

ESTIMATE.

1,520,000 pounds of wire, including the cost of manufacturing, raising and adjusting the cables, at 10 cts.	$152,000
40,000 pounds No. 12 wire, in the suspenders, at 12 cts.	4,800
190,000 pounds bar iron in the anchorage, at 7 cts. -	13,300
31,000 pounds bar iron in bolts, for the flooring, parapets, &c., at 7 cts. - - - - - -	2,170
50,000 pounds cast iron, for saddles, rollers, roller plates, &c., at 4 cts. - - - - - - -	2,000
47,500 cubic feet of timber in the flooring and parapets, including framing and raising, at 30 cts. - -	14,250
600 cubic yards rock excavation in the fastening chambers, at $7.00, - - - - - - -	4,200
2200 cubic yards masonry in the towers, at $10.00 -	22,000
7100 cubic yards masonry in the abutments, at $4.00,	28,400
7250 cubic yards masonry in the arches, piers, and wing-walls, at $7.00, - - - - - -	50,750
500 cubic yards masonry in the fastening chambers, or anchorage, at $8.00, - - - - - -	4,000
Total cost, - -	$297,870

Or, in round numbers, I estimate the entire cost of the bridge at $300,000.

If the structure were in all respects the same, excepting only that the railway track were left out, but preparation made for its introduction; and four of the cables, which would then be unnecessary, were temporarily dispensed with, the cost of the bridge would be reduced to $250,000. No change of plan would be required to build it in this way. It would merely involve the omission of the stone flagging, the upper and lower girders, and four of the cables; all of which might be supplied whenever they would be required for the use of a connecting link of railway. The anchor-

age would, however, need to be prepared for these additional cables in the progress of the work.

Still, I think it scarcely probable that the construction of the rail road track can be delayed, beyond the completion of the bridge. Indeed, if the erection of this bridge be authorized by Congress, I hesitate not to say that the railway to connect the northern and southern lines would be promptly undertaken as a private enterprise. All that now stands in the way, and prevents this connecting link from offering inducements sufficient to justify parties in undertaking the work, is the want of a charter for the road, and the need of this bridge across the Potomac.

OF THE STIFFNESS OF SUSPENSION BRIDGES.

Considering the suspension bridge in its simplest form, as without any rigidity or stiffness of its own, and resisting displacement solely by its weight, or vis inertia, it is easy to calculate the utmost movements which will be produced by the application of given forces. A very simple rule, deduced, however, from a very profound and elaborate investigation, will suffice for such computations, when we know the weight of a bridge, the span and deflection of the curve formed by the cables, and the weight of any extraneous load brought upon the centre of the flooring. This rule, when no allowance is made for the proper resistance of the flooring itself, is as follows:—

Multiply the sagitta, or deflection of the curve of the cables, in feet, by the weight in tons placed in the centre of the flooring, and divide the product by twice the

weight of the bridge, in tons: the result will be the depression, or bending, which that weight will produce in the centre of the bridge, expressed in feet—provided there be no stiffness in the flooring. (See Note B.)

Let us now suppose that a locomotive engine of 15 tons weight were brought on the centre of the flooring of the proposed bridge. In this case the weight of the bridge is 1594 tons; and the sagitta, or deflection of the cables, is 65 feet.

The rule will then give

$$\frac{65 \times 15}{2 \times 1594} = \frac{306}{1000} \text{ of a foot.}$$

Or, a locomotive engine weighing 15 tons, placed in the centre of the arch of this bridge, would produce a depression in the flooring, of three-tenths of a foot, in the case assumed—viz: that the flooring itself is without strength or stiffness. Of course, if the framing offer any resistance, or if the bridge cannot rise at the haunches of the inverted arch, the depression must be less. But it would be superfluous to contend that a depression of *three-tenths of a foot*, or, indeed, of a foot, in an elastic bridge of 1000 feet span, is utterly insignificant, and would be entirely harmless.

The Wheeling Bridge, of which the span is 1010 feet, rises or falls frequently 8 or 10 inches, in the course of a few hours, from mere changes of temperature. It is, in truth, often depressed eight inches by the passage of a loaded six-horse team along the flooring; and there are frequently several of these teams upon it at the same time. Two loaded six-horse teams meeting on the arch of that bridge, will depress the

flooring 15 or 16 inches; yet a person crossing at the same time would be unconscious of any such flexure in the arch. The movement is, in fact, perfectly harmless. A depression of 16 inches in a bridge of a thousand feet span produces the same angular motion, or the same strain on the material of the flooring, as a depression of $1\frac{6}{10}$ inch in an arch of 100 feet span.

To produce a depression of 16 inches—such as often occurs in the Wheeling Bridge—in the structure before us, would require a weight of 66 tons to be concentrated in the middle of the arch. But in the practical use of a bridge, no such load can be concentrated on any point of its flooring. The rail road train is distributed over many feet, and the depression is consequently greatly reduced, both because of this distribution, and because of the stiffness of the bridge itself.

Yet 16 inches, an amount of bending often experienced in the Wheeling Bridge, is really of no consequence. It is not much more than sometimes occurs in the hulls of the Western steamboats, from improper loading, without causing the seams to open or producing leakage.

The proposed bridge over the Potomac will possess more than four times the resistance to displacement that is offered by the Wheeling Bridge, for the reason that it is more than four times as heavy; and it will present a still greater resistance, for the further reason, that the cables are drawn taughter; and, finally, for the additional reason, that the flooring is made purposely of great strength, so that the heavy weights which come upon it, instead of pressing on a given point, may be distributed to the right and left along the track. Yet

the Wheeling Bridge, even as it is—built for common travel—is fully competent to bear the weight of an ordinary rail-way passenger train, without injury, or danger to its security.

It might seem that the vibrations of a suspension bridge would be materially increased by the speed of the train. Under certain circumstances this is so. Yet experiment shows that the extent of the depression produced by a given weight *is less* when the team which produces it is moving across the flooring than when resting quietly upon it. In other words, that if a team be brought upon the flooring of a bridge, and the depression thereby produced be carefully measured, while the team is at rest; and then measured again when the same team is moved briskly across the flooring, the depression will be perceptibly less in the second than in the first instance.

I have made no particular computation, in this report, of the effect of *the winds* in causing vibration; because we have abundant experience to show that the bridge will be safe against the strongest hurricanes. A suspension bridge resists the action of the wind by its own weight; and we know that bridges of one-fifth the weight of this—such as the Freibourg Bridge—have resisted the heaviest blows and sometimes tornadoes.* The most violent hurricane would assail this bridge without danger to its safety.

* The cables are inclined towards the axis of the bridge, so as to serve also as lateral stays. But still it is the *weight* of the structure that makes this lateral support effective.

OF THE EFFECTS OF VARIATIONS OF THE TEMPERATURE.

Suspension bridges, like all other bridges, and structures supported by iron, are subject to perpetual elevations or depressions consequent on changes of temperature. As the temperature of the air rises, the cables undergo a corresponding dilatation, and the flooring is consequently depressed. The value of this depression may be very closely calculated by the following simple rule:—

Divide three-eighths of the span of the cables by the sagitta of the curve, and multiply the quotient by the dilatation of half the length of the cables. The result will be the depression in feet. (See Note C.)

For an application of this rule to the present plan—where the span is 1000 feet, the sagitta 65 feet, and half the length of the cables 700 feet—we must first ascertain the dilatation of the cables due to a change of one degree of temperature.

The average result of experiments on the dilatation of iron is $\frac{1}{150000}$ for each degree of Fahrenheit. The dilatation of half the length of the cables, or 700 feet, will therefore be

$$\frac{700}{150000} = \frac{7}{1500} \text{ of a foot}$$

for each degree.

Consequently, by applying the preceding rule, we shall have

$$\frac{3 \times 1000}{8 \times 65} \times \frac{7}{1500} = \frac{7}{260} \text{ of a foot,}$$

for the sinking of the platform of the bridge, consequent on each degree of elevation of the temperature.

The extreme variation at Georgetown occasionally approaches 100° of Fahrenheit: and the extreme change in the height of the flooring might, consequently, amount to

$$\tfrac{70}{26} = 2\tfrac{7}{10} \text{ feet};$$

or the bridge might possibly be two feet and seven-tenths higher in the extreme cold weather of winter, than in midsummer.

This might seem to be a dangerous movement. But no practical inconvenience whatever is found to result from it. The bridge rises and falls, but no eye discovers the movement of two or three feet distributed along a platform 1000 feet in length. The same movements take place also in the *rigid frames* of cast iron bridges, some of which must rise and fall not less than six or eight inches in the variations of the year. The iron houses in which we live undergo similar changes. They are taller at midday than at midnight, and taller in the summer than in the winter. Iron ships are equally liable to be warped. The hull of an iron steamer at anchor, struck on its broadside by the morning sun, must turn its bow and stern to the west; and in the evening, when the sun shines on the opposite side, the boat is necessarily warped in the opposite direction. The elasticity of the material compensates for these movements, and no injury results.

OF THE FITNESS OF SUSPENSION BRIDGES FOR RAIL ROAD PURPOSES.

There is still an undefined prejudice against the application of suspension bridges to rail road purposes;

yet it is doubtful whether any engineer will undertake now to deny the practicability of constructing a safe and sufficient bridge for the passage of locomotives and their trains, upon this plan. Indeed, the denial itself would involve an absurdity apparent, on reflection, to the intelligence of every practical mind. We know that a single strand of wire stretched between two fixed points, at a given distance, and in a given manner, will bear safely a given weight. We know that two strands, stretched in the same manner, will bear twice that weight with equal safety; and that a million of strands, under like circumstances, will bear a million times that same weight. If the single strand will only bear with safety a hundred pounds, a million strands will bear with equal safety, a million times 100 pounds, or fifty thousand tons. There is nothing therefore to limit the capacity of the bridge to sustain, but the limit which we set to the amount of material to be used. We can make a suspension bridge of wire with equal certainty whether it be intended to bear the weight of a horse and carriage, or to bear the weight of a hundred locomotives. The problem is precisely the same; its solution, in either case, equally certain. The principle is fixed, the amount of material and cost are the only variable elements.

But, while it is admitted on all hands that such bridges may be made strong enough to bear any given weight, there is yet often a lurking suspicion that they may not be steady enough for the use of heavy engines and their trains. But this is, in fact, precisely the same error as the other, and equally clear to demonstration that it is so.

If a single strand of wire be stretched between two fixed points, it matters not what may be the dimensions of that strand, it is evident that a weight may be chosen so small that when drawn or rolled along it, no appreciable, or at least no hurtful vibration, will be produced thereby.

If then, a single strand is unmoved, or not hurtfully moved, by a given weight, ever so small, it is again clear that a million of such strands will bear a million of such weights, with equal steadiness. There is obviously no limit to the stability or inertia that may be given to a suspension bridge—for the very chains which support it may be made heavy enough to be practically proof against oscillations in a vertical direction.

It is, in fact, *the weight* of a suspension bridge that gives it stability. The heavier it is, the more difficult it is to displace.

A light bridge may be shaken by the shock of light bodies; while a heavy bridge, under like circumstances, can only be equally moved by bodies heavier in proportion as its own weight is heavier.

This, it is true, is mere general reasoning leading to results that are apparent to every one. But I treat the subject in this mode for the reader who will not consent to the more precise deductions of mechanics.

In short, to render a suspension bridge steady, we must properly proportion, not only the strength, but *the weight* of the bridge, to the weight of the moving burthens which it is to support. If we adopt the proportions which experience shows to be barely sufficient for a foot bridge, in a structure intended to bear the weight of farm wagons, the bridge will certainly

shake, and appear to be dangerous. And, on the other hand, if we adopt the proportions which would be safe and sufficient for farm wagons, in a bridge designed to sustain droves of fatted cattle, or such loaded six-horse teams as are used on the National road, it will certainly be unsteady and may seem to be unsafe. And so, if we adopt proportions fitted only for six-horse teams or droves of heavy oxen, in a bridge intended to support locomotives and heavy trains of freight cars, it also will oscillate and bend unduly beneath its burthen. These facts, though they ought to be perfectly apparent, have not been considered by the opponents of railway suspension bridges; who draw their hasty conclusions from experience obtained upon light bridges suitable for common travel, and misapplied to rail road purposes.

The suspension bridge across the Tyne, on the Stockton and Darlington Rail Road, was a signal failure, because it was a common road bridge, of a very light pattern, subjected to the heavy usage of a coal railway. I have seen that bridge, and speak with personal knowledge on this point. It should never have been applied to any such duty; or rather, it should have been made five or six times as heavy as it was.

The same inexperience, however, has led to the failure not only of a single suspension bridge, but of nearly all the first rail road bridges, of every description, on the great thoroughfares of this country.

The fact that all—I believe *all*—the first wooden bridges failed on the Reading road, and on the Baltimore and Ohio and other early lines, as the weight of the locomotive engines was increased, is notorious. But it

was not concluded from that fact that wooden arches, or wooden trusses, were inadequate to rail road service. It was merely concluded that heavy locomotives and freight cars required heavier and stronger framings for their support than were needed to bear the weight of light engines or common teams. These early bridges were therefore reconstructed—often on the same plan—but they were made stronger.

In all works of art we must proportion the structure to the duties which it has to perform.

A foot bridge erected by the writer, for a temporary purpose, 800 feet long, and only *three feet wide*, and suspended more than 200 feet in the air, quivered under the weight of a man, and oscillated greatly under the movement of a crowd. But that bridge weighed only *twenty-five pounds* for each lineal foot of the flooring. Yet the Wheeling Bridge, of more than a thousand feet span, is steady enough under trains of heavy wagons, and does not vibrate injuriously beneath droves of the heaviest bullocks. The reason is, simply, that the Wheeling Bridge, instead of weighing only 25 pounds per lineal foot, weighs more than 800 pounds per foot; and is, consequently for that reason alone, more than thirty times steadier, or capable of bearing loads more than thirty times as great as the foot bridge at Niagara, with no greater vibration. But the weight of the bridge now proposed will be *four times as great as that of the Wheeling Bridge;* its cables will be four times as strong, and its flooring will be framed with a view to the distribution of the pressure of the trains.

The day seems to be nearly gone when a practical or scientific truth, susceptible of direct demonstration,

can be resisted on the authority of a popular prejudice. That which can be demonstrated will now be believed. In the earlier periods of practical science, it was enough to doubt, in order to condemn, a new proposition. Information was spread slowly, and confidence was won by a painful struggle. Long after the locomotive was invented, its power to propel itself forward was doubted, because it was supposed that the wheels would slip on the rails. To guard against this imaginary difficulty the engine was provided with claws, and other rude appendages, equally unnecessary and awkward, to enable it to push or drag itself along. But even then it was perfectly demonstrable, without a single item of additional information, that no such difficulty existed.

The difficulty which Brindley encountered when, 90 years ago, he proposed to construct a stone aqueduct across the Irwell, at an elevation of 39 feet above the stream, is matter of history. The project was considered "wild and extravagant." Consultation was suggested. A gentleman of official eminence was accordingly called, who, says the historian of the work, being conducted to the place where it was intended that the aqueduct should be made, ridiculed the project, and remarked contemptuously, "that he had often heard of castles in the air, but never was shown before where any of them were to be erected." But the aqueduct was built for all that; and there are engineers enough now, both in Europe and America, who would take such an aqueduct as that on a carriage, and launch it across the Potomac.

The power to navigate the ocean by steam, was de-

nied for years after the world was in possession of all the art and means for its accomplishment, in the unfounded assumption that the vessel could not carry fuel enough for the voyage. Nay, we are told, and it seems to be matter of history, that for 30 years after iron rails for rail roads were first attempted, they were laid aside, and their fitness denied, on the ground that they would not bear the weight of the heavy coal cars in use. Thirty years, it seems, passed by before it was perceived that by making the cars lighter or the rails stronger, the application might be made.

But in this age it would be strange indeed, if after we know that suspension bridges have been made strong enough to bear footmen; and increased from that limit until they were strong enough to support teams; then trains of artillery, and droves of cattle, and columns of troops—it would be strange indeed, with this experience, if we could not comprehend that by making the same sort of bridges heavier and stronger, we could make them bear safely the weight of a locomotive, or if need were, of a ship of the line.

Certainly no such doubt will be felt. Twenty years ago the first question asked of every new project—canal or rail road—was, Is it practicable? But who asks now whether a rail road is practicable anywhere?

The writer of this Report is at this time constructing a rail road across the Blue Ridge, in Virginia, to be traversed by locomotives, on which the *grades* are 295 feet per mile; yet no one will question its success.*

* February, 1854. This work will be in use in the course of a few weeks.

I have no fear that the practicability of this bridge will be doubted. Twenty years ago, when I proposed a suspension bridge across the Potomac, for common travel, in place of that long causeway called "a bridge," from which you have so long suffered, and of which you have so often and so loudly complained, the practicability of the plan was a subject of doubt.* But those doubts have been set at rest by the Fairmount, the Niagara, and the Wheeling bridges, as they ought to have been by numerous works then existing in Europe. To prove that these bridges might be made heavier and stronger, and hence capable of bearing greater weights, is a difficulty of a secondary order.

I have no fear of the result of the investigation. The tribunal before which you appear is just that from which you may look for an enlightened decision. An American Congress will not deny the practicability of a work demonstrably safe.

If the appropriation is refused, it will be on other grounds.

Your obd't servant,

CHARLES ELLET, Jr.

Civil Engineer.

Philadelphia, *December* 15, 1852.

* For this plan, see Congressional Documents for 1832.

NOTES.

NOTE A.

The formula for calculating the tension in the cables at the points of suspension, is

$$T = \frac{p\,h}{2\,f}\,(h^2 + 4\,f^2)^{\frac{1}{2}}$$

Where T is the tension;

h, half the distance between the points of suspension in feet;

f, the sagitta of the curve in feet; and

p, the weight of each lineal foot of the suspended portion of the bridge; or bridge and load.

The horizontal tension is

$$Q = \frac{p\,h^2}{2\,f}$$

NOTE B.

The formula for calculating approximately the depression of the flooring which will be produced by a given weight placed in the centre, is

$$f' = \frac{\pi\,f}{4\,p\,h}$$

in which f' is the depression in feet, π the weight producing it, and f, p, and h, as above.

NOTE C.

The formula for calculating the depression of the flooring produced by any elongation of the cables, consequent on additional tension, or changes of temperature, is

$$f' = \frac{3\,h}{4\,f}\,c'$$

in which c' is the elongation of half the length of the cables.

The example in the text must be regarded as an extreme case. Two feet is probably the greatest range that will ever be experienced.

NOTE D.

The actual length of the Long Bridge is within a fraction of one mile, or *about four-fifths of a mile greater* than that of the proposed Georgetown Bridge. If the flooring were elevated, as it ought to be, to protect the navigation adequately, its length would be somewhat increased: and I have therefore assumed *one mile* for the difference of the lengths of the two bridges in estimating the loss of time.

If the calculation on page 7 had been made for a speed of eight miles an hour, and a difference in the lengths of the bridges of four-fifths of a mile, that loss would have been $4\frac{2}{5}$ minutes.

For a speed of six miles an hour, and a difference of four-fifths of a mile, it would have been $6\frac{2}{5}$ minutes.

By crossing the Potomac at the Observatory hill, there would be a small saving of distance. But this suggestion, if we have respect for the navigation, also involves the necessity of a very long, high, and costly bridge; besides the loss of time due to the diminished speed in traversing the City of Washington more than two miles, where, for a considerable portion of the distance, it is already densely built up.